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Soviet Solid-State Dye Lasers: Technology Available for Frequency-Agile Military Laser Systems [REDACTED]

A Scientific and Technical Intelligence Report

This paper was prepared by [REDACTED]
with contributions from [REDACTED]

[REDACTED] Office of Scientific and Weapons
Research. Comments and queries are welcome and
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SW 90-10066
November 1990

Soviet Solid-State Dye Lasers: Technology Available for Frequency-Agile Military Laser Systems [REDACTED]

Summary

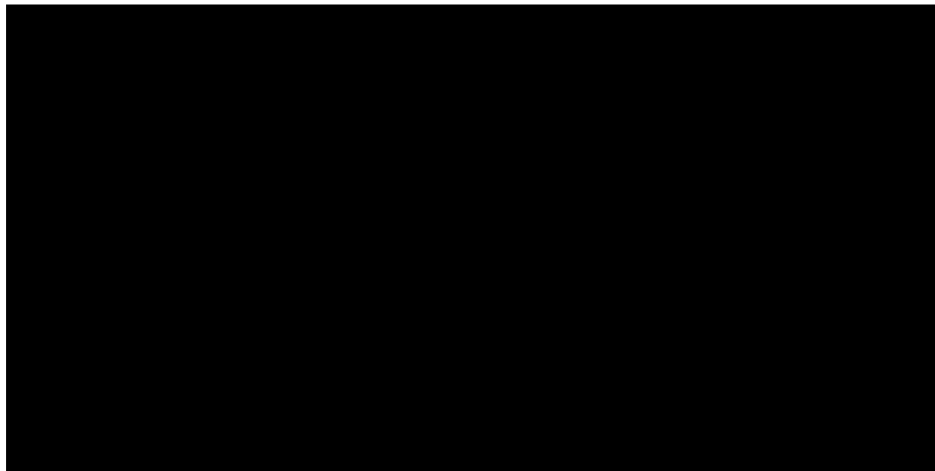
*Information available
as of 1 September 1990
was used in this report.*

The Soviet military evidently is preparing to deploy a variety of solid-state dye laser systems designed to have variable output wavelengths in order to complicate Western countermeasures. Sustained Soviet R&D of dye laser technology provides the key evidence of a long-term interest in frequency-agile lasers. [REDACTED]

the military will now be able to proceed with the design and development of specific systems for target acquisition, tracking, and blinding. [REDACTED]

[REDACTED] has identified some of the systems that the Soviet military wants to pursue, but we believe there may be others. Initial systems, including a countermeasure-resistant target locator, could be deployed beginning in the mid-1990s. [REDACTED]

The Soviets have proven, solid-state tunable dye laser technology ready for incorporation into military and civilian development programs. In addition to offering frequency agility, these solid-state dye lasers are rugged, reliable, and well suited to battlefield, airborne, and spaceborne applications. The laser technology results from nearly two decades of military-sponsored research intended to support a variety of applications. Applications, in addition to the countermeasure-resistant target locator, include blinding systems and a laser to damage enemy optical systems on the battlefield. The Soviets also are interested in upgrading previously developed military laser systems to make them resistant to simple (single-frequency) countermeasures. [REDACTED]



The USSR has the advantage of having the world's only solid-state dye laser technology. Moreover, the Soviets are investigating other laser technologies that offer frequency agility and high reliability. Because of their demonstrated interest in this field, we expect the Soviets, despite defense cutbacks, to continue pursuing new tunable laser technologies. Some of these technologies probably will be available to military system designers in the next few years. [REDACTED]

To defeat Soviet solid-state dye laser systems, the West will require wavelength independent countermeasures. Also, a means must be found to reduce the optical cross sections of all optical systems to contend with the tunability associated with a Soviet low-power-level laser target locator. To defeat tunable laser damage weapons, ways must be found to limit the intensity of light passing through Western optical systems. Finally, with the potential Soviet development and use of solid-state dye technology, a similar threat to the West could emerge from the Third World or subnational organizations through the export of Soviet solid-state dye elements. [REDACTED]

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Scope Note

Soviet scientists and engineers have been developing solid-state dye laser technology—with strong support from the Soviet military—for more than 20 years. In this paper, we examine the technical objectives, milestones, and general progress in the technology development. We also assess known, likely, and possible Soviet military applications of this tunable laser technology, and we estimate the likelihood of development and the deployment times for these military systems. [REDACTED]

The principal results of our analysis are intended to be used by US military systems designers to develop appropriate countermeasures to future Soviet laser systems. In addition, the unique Soviet approach to the development of rugged tunable laser technology may be of value to the US laser research community. [REDACTED]

[REDACTED]

Soviet Solid-State Dye Lasers: Technology Available for Frequency-Agile Military Laser Systems

Soviets Quick To Recognize the Significance of Tunable Solid-State Lasers

In the early 1960s, scientists throughout the world were rapidly developing new laser concepts. Lasers based on solid-state materials, including glasses and crystals, proved to be compact, rugged, and generally reliable. In the USSR and the West, solid-state lasers quickly became critical components in military and industrial systems. As rangefinders and target designators, solid-state lasers proved valuable on the battlefield. One limitation on their use, however, was that the emissions of solid-state lasers could not be tuned to a desired wavelength. Being restricted to a few fixed wavelengths made these lasers susceptible to a variety of countermeasures.

For those applications requiring tunability, scientists in the USSR and the West turned to lasers based on organic dyes in liquid solutions. With a selection of dyes, a liquid-dye laser could be tuned from near infrared wavelengths through the entire visible spectrum. However, the liquid-dye lasers were bulky, unreliable, and generally poorly suited to applications outside the laboratory.

In 1967, two US scientists published a technical paper on a laser based on an organic dye contained within a solid polymer matrix. They had noticed that a plastic drafting square composed of dye-colored polymethyl methacrylate—commonly known as lucite—when inserted into a powerful laser beam would itself lase at a wavelength determined by the dye in the plastic. They also noted, however, that the lasing efficiency was low. Little followup research was conducted in the United States.

Soviet scientists, on the other hand, were quick to grasp the potential of solid-state dye lasers. In introductory sections to technical papers published in the early 1970s, the Soviets noted that, as compared with dyes in liquid solution, dye-activated solid polymer lasers potentially could be made more simple, more

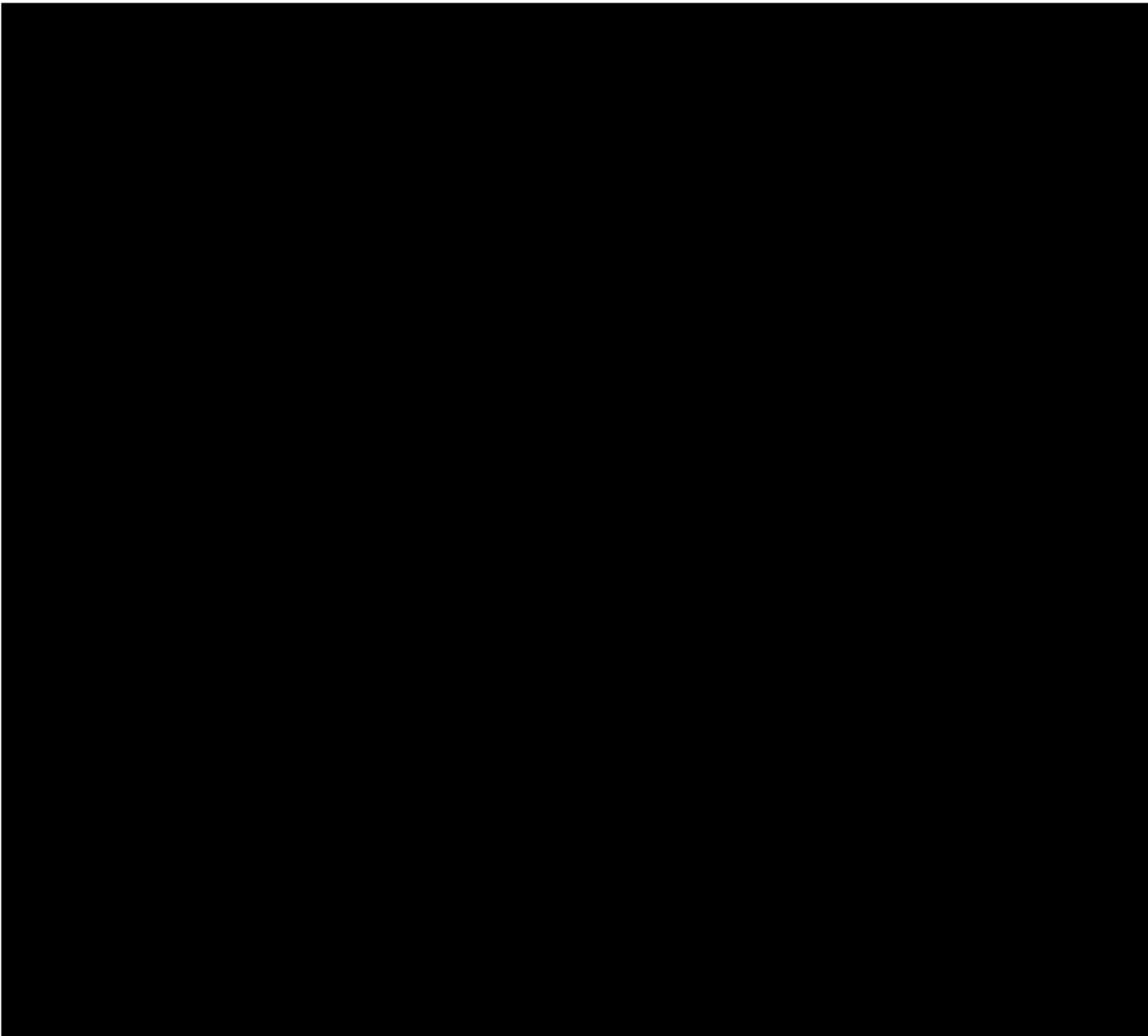
compact, easier to manufacture, and much more reliable in field use.¹ It is not clear if the Soviets had specific military applications in mind at the outset of their research into solid-state dye lasers, but we believe that the Soviet military had these general advantages in mind when it sponsored the research activity from which a variety of applications could evolve.

Soviet Military Funds the Development of a Technology Base for Military Applications

the Soviet military has funded most of the research in solid-state dye lasers.

solid-state dye technology was developed to provide Soviet laser systems with variable output wavelengths in order to defeat Western optical protection and to resist countermeasures. Throughout the 1970s and 1980s, the Soviet military planned to become increasingly dependent on laser systems to acquire information on enemy targets and to direct

¹ Liquid-solution dye lasers require a large reservoir of dye solution and a circulatory pumping system.



precision-guided munitions against them. With the expectation that reliance on laser systems would grow, the Soviets also had to address the threat of potential countermeasures. Enemy forces could detect Soviet fixed wavelength laser emissions and direct fire back onto critical surveillance targets. Soviet smart munitions that focused on target reflections or emissions could be spoofed with same-wavelength lasers. Solid-state dye technology offered the Soviets a means to

vary the laser output across a broad wavelength spectrum, thus defeating simple countermeasures.

Soviet solid-state dye technology probably was developed with the broad goal of providing Soviet military systems designers with rugged, frequency-agile lasers for integration into a variety of ground, airborne, and

spaceborne laser applications. The directions of scientific research, as well as statements by Soviet scientists in technical review articles, suggest that the technical goals of the Soviet research program were generally intended to support a broad range of applications. We know of some specific applications, discussed later in this report, but Soviet research activity seems to have been aimed at a wide range of possible uses of dye lasers. [REDACTED]

The directions taken in Soviet solid-state dye research indicate a desire to achieve frequency agility while retaining the overall reliability and performance of existing fixed wavelength lasers. For example, the Soviets investigated organic dyes with emission bands from the near infrared through the near ultraviolet range of the electromagnetic spectrum, indicating no application-specific band of interest. Single- and multiple-pulse optical damage of polymer hosts were investigated with the goal of achieving "equivalent performance to optical glass." The implied objective was to develop a solid-state dye element that could be incorporated into existing optical systems without limiting overall system performance. [REDACTED]

Soviet technical review articles published in the early 1980s described research goals in terms of classes of applications. Authors wrote that solid-state dye lasers would be particularly well suited to ground, airborne, and spaceborne laser applications because such lasers could operate under a wide range of temperatures and under zero-gravity conditions. Liquid-solution dye lasers, by comparison, already were perfectly adequate for laboratory and industrial use. [REDACTED]

Technical Objectives and Milestones of the Soviet Program

At first, Soviet scientists suggested that solid-state dye laser technology would mature quickly; however, this belief was not the case. Researchers from a variety of Soviet institutes soon began to identify numerous impediments to the development of this technology. They included:

- The optical strength of the solid host material (its resistance to optical damage).
- The optical strength of the dye (resistance to photobleaching).
- The optical quality of the combined material [REDACTED]

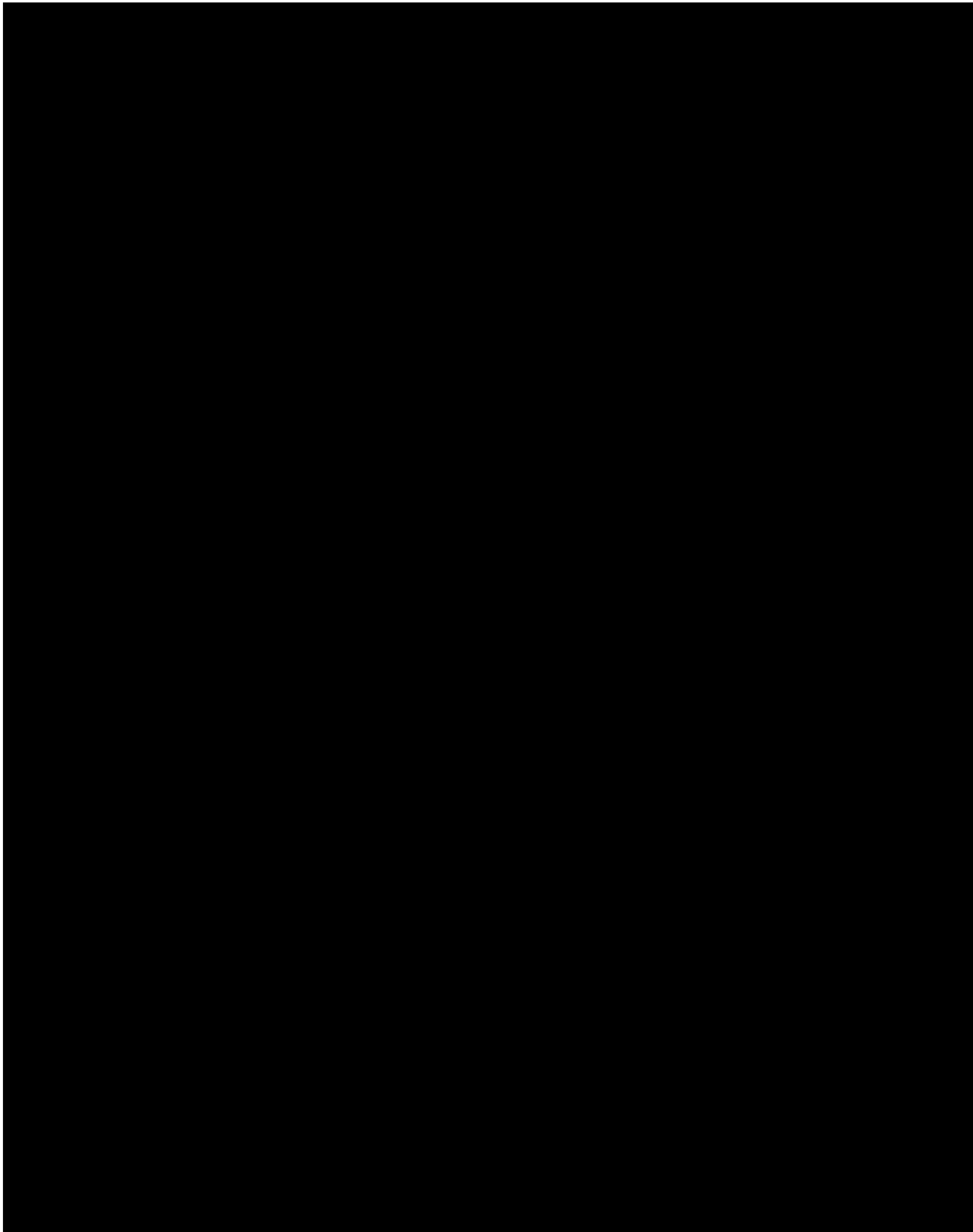
Soviet R&D Cycle

Soviet military systems are developed through a series of highly regulated stages. The process:

- *Begins with a forecast (prognoz).*
- *Progresses into several stages of Scientific Research Work (nauchno-issledovatel'skaya rabota, or NIR).*
- *Proceeds to Experimental Design Work (opytnokon-struktorskaya rabota, or OKR).*
- *Enters into production (proizvodstvo).* [REDACTED]

Major decision points mark the transition from one stage to another. Research to lay the scientific-technical base for use in future military systems is conducted within NIR. Requirements generation, assessments of technology for new systems, and design alternative evaluations also are conducted during NIR. Design and construction of system-specific test components and prototypes of items intended for production are accomplished in OKR. [REDACTED]

To overcome these impediments, formal scientific research work or NIR (see inset) was initiated in the early 1970s. A variety of Soviet institutes teamed up to solve the specific problems [REDACTED]. As the research progressed, new technical problems were encountered and additional research efforts were undertaken. Several alternative solid-dye technologies were developed in parallel by competing institutes.



Solving the First Challenge:**Single-Pulse Host Optical Strength**

Primarily from openly published technical reports, we believe that the Soviets in about 1970 first recognized the single-pulse optical strength of polymer materials as a limiting factor in solid-state dye laser development (see figure 3). In a 1973 technical paper, A. A. Manenkov of the Institute of Physics in Moscow described experimental results of laser-induced optical breakdown of polymethyl methacrylate and other optically transparent polymers. Manenkov determined that the optical strength of commercial polymethyl methacrylate was 0.1 megawatt per centimeter squared (MW/cm^2) in a nanosecond pulse—several orders of magnitude lower than for optical glass and far too low to be used as a practical laser material. In what was to become the focus of more than a decade of research, Manenkov suggested that the optical strength of polymethyl methacrylate could be improved by reducing the concentration of impurities.

Working in conjunction with the Scientific Research Institute of Organic Intermediate Products and Dyes, Manenkov developed a procedure for manufacturing optical-quality polymethyl methacrylate. According to open technical papers and statements by Manenkov, special procedures were selected for filtering the methyl methacrylate monomer to reduce particulate impurities. In addition, special polymerization procedures were adopted to reduce the concentration of voids and other imperfections. On the basis of the optical strength of polymethyl methacrylate reported by the Soviets at international conferences and in open publications, we believe that, by the late 1970s, the Institute of Physics in Moscow and the Scientific Research Institute of Organic Intermediate Products and Dyes had developed samples with a single-pulse optical strength of about $100 \text{ MW}/\text{cm}^2$ —approaching that of optical-quality glass.

Optical-quality polymethyl methacrylate appears to have entered limited production in the early 1980s, but quality control may have hindered practical applications. Soviet scientists at a variety of institutes published articles in the early-to-middle 1980s describing laser systems

incorporating polymethyl-methacrylate-based lenses. These lenses, however, may have come from the Institute of Physics in Moscow rather than from industry. Manenkov complained repeatedly at international conferences in the early 1980s that Soviet industry was not able to match the quality of polymethyl methacrylate produced at his institute. In particular, he stated that industry could not maintain the purity required to achieve sufficient optical strength. We have insufficient information to determine exactly when Soviet industry solved this problem, but, by the mid-1980s,

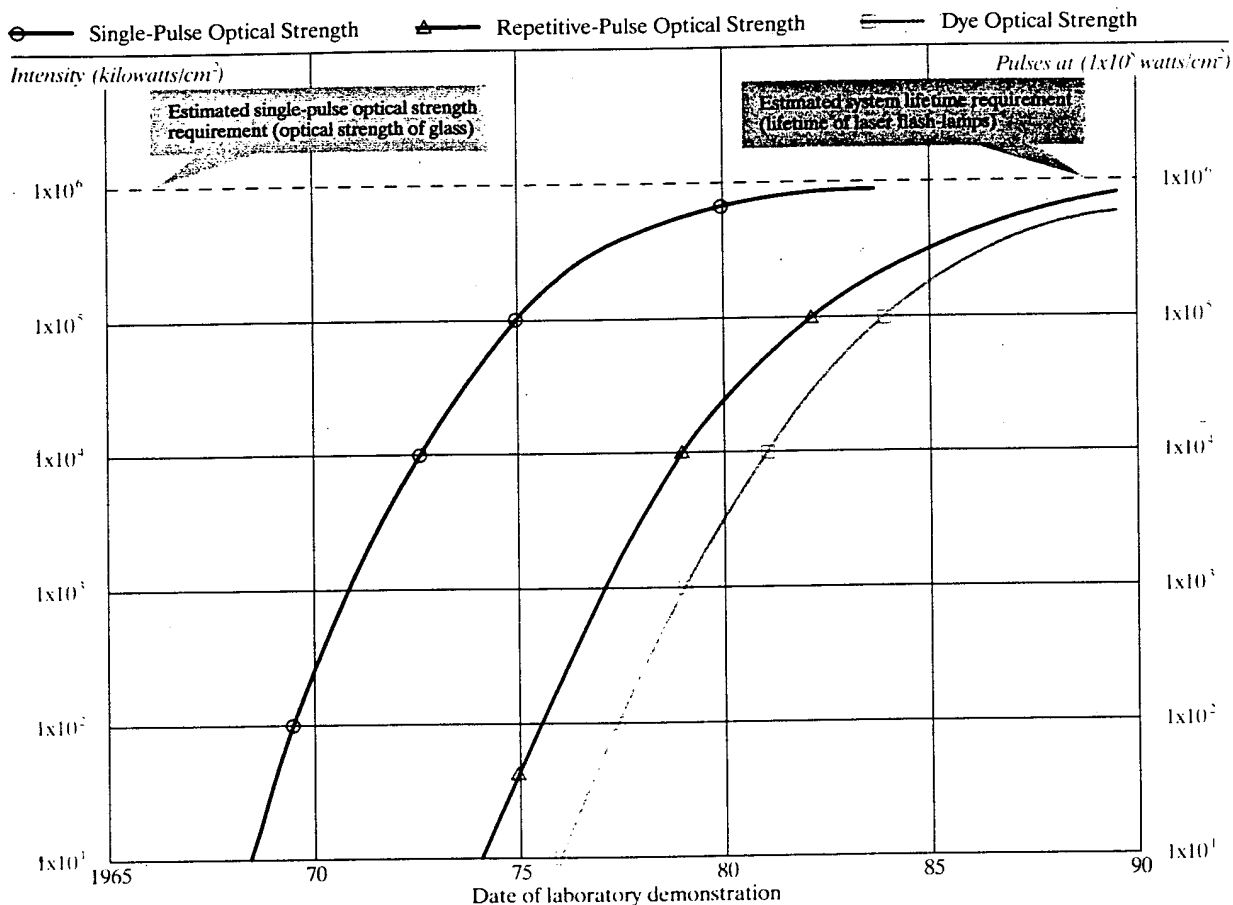
Soviet scientists appeared to have sufficient supplies of optical-quality polymethyl methacrylate as determined by their published reports.

A New Problem: Optical Strength of the Host Under Repetitive Pulses

On the basis of their published results, we believe Soviet scientists realized in the late 1970s that, after repeated use, optical damage would occur in polymethyl methacrylate at significantly lower intensities than the single-pulse damage limit. Experiments reported in scientific papers in the early 1980s demonstrated clearly that, unlike glass, optical elements made of polymethyl methacrylate showed catastrophic damage after repetitive laser pulses of several orders of magnitude of less intensity than the single-pulse damage limit—still inhibiting most practical applications. In retrospect, a fundamental shift in the Soviet technical literature occurred in the late 1970s as the Soviets geared up to address this limitation.

The technical literature indicates that several Soviet institutes put forth theories to explain the anomalous low-repetitive-pulse damage limit. Scientists at the Scientific Research Institute of Organic Intermediate Products and Dyes suggested that the effect was due to overheating and carbonization of the polymer in the immediate vicinity of any light-absorbing impurities. The region of absorption and resultant damage would grow from pulse to pulse. Their theory suggested no ready solution other than trying to further reduce the initial concentration of impurities.

Figure 3
Technical Progress in Developing
Solid-Dye Technology



The Soviet solid-dye laser program encountered three major impediments: 1. raising the single-pulse optical strength of polymethyl methacrylate to that of optical quality glass (1×10^6 watts/cm²); 2. raising the repetitive-pulse optical strength of polymethyl methacrylate up to the estimated system lifetime (1×10^5 pulses); and 3. raising the lifetime of the laser dye incorporated into the polymethyl methacrylate up to the estimated laser system lifetime (1×10^5 pulses). The data points were derived from Soviet technical publications (adjusted to reflect the inherent publication delays).

while the curves provide our overall best estimate of progress.

Optical Strength Requirements

A low-energy, short-pulse dye laser typically emits about a joule of energy in about 10 nanoseconds and has a cross section of about 1 cm². These operating characteristics require that the dye element have a single-pulse optical strength in excess of 100 megawatts/cm². An optical strength of 1,000 megawatts/cm² would be adequate for most applications.

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Manenkov, on the other hand, suggested that the growth of absorbing defects was related to the viscoelastic properties of the polymer, not to its chemical composition. This theory implied that, by modifying the viscoelastic properties, the repetitive-pulse damage limit could be made to converge on the single-pulse damage limit, gaining at least several orders of magnitude improvement. In a 1979 technical paper,

Manenkov reported experimental results supporting his theory. In these experiments, the viscoelastic properties were varied by incorporating a highly volatile plasticizer in the polymer or by altering the temperature of the samples over a broad range (between -60 and 80 degrees Celsius). In each case, the

single-pulse, bulk-damage threshold was determined by exposure of the polymer to a 20-nanosecond ruby laser pulse. The repetitive-pulse optical strength was determined by repeated exposure to radiation pulses having a fixed subthreshold intensity, and the strength was reported as the number of laser pulses that could be applied before the appearance of macroscopic (>100 meters) damage in the matrix. The results showed a definite correlation between the viscoelastic properties and the optical strength characteristics. [REDACTED]

Soviet technical literature indicates that in the early 1980s Manenkov was successful in fabricating polymethyl-methacrylate-based optical elements with a repetitive-pulse optical strength equal to glass. In 1983, Manenkov coauthored a classic paper entitled "Transparent Polymers: A New Class of Optical Materials for Lasers" with A. M. Prokhorov, deputy director of the Institute of Physics in Moscow, and V. S. Nechitailo, team leader from the Scientific Research Institute of Organic Intermediate Products and Dyes. This paper reviewed the formulation of Manenkov's optical damage theory, the experimental confirmation of the theory, and the development of polymethyl methacrylate capable of withstanding repetitive optical intensities of greater than 100 MW/cm² based on implications of the theory. Manenkov concluded by stating that transparent polymers already are available that may be competitive with traditional materials in high-optical-strength elements (for example, lenses or prisms) and they undoubtedly have advantages in specific laser components as active elements (solid-state dye lasers) and passive switches. [REDACTED]

Few technical papers were published after 1983 on the optical strength of polymethyl methacrylate, suggesting that this aspect of the research had been completed. In addition, the use of optically transparent polymethyl methacrylate in Soviet (nonlasing) optical elements became common by about 1985, suggesting that Manenkov's polymethyl methacrylate had entered series production. It is possible, therefore, that the Soviets made a decision to proceed with the development of military dye lasers at about this time. As discussed below, however, other technical problems arose that probably forestalled such a decision. [REDACTED]

The Last Hurdle: Dye Optical Strength

The incorporation of dyes into solid-state host material created new problems. Scientists from the Scientific Research Institute of Organic Intermediate Products and Dyes identified the lifetime of the dye as a critical issue. In a 1976 technical paper, V. S. Nechitailo noted that dye molecules in a polymer element were rapidly denatured due to a photobleaching process. He suggested that new dyes were needed with greater resistance to photobleaching and that methods of stabilizing dye molecules in a polymer matrix would be required. [REDACTED]

[REDACTED] in 1989, A. A. Manenkov stated that he had successfully increased the lifetime of solid-state dye elements up to that of the host material by encapsulating alcohol and other additives with the plasticizer. According to Manenkov, the alcohol interacts with dangling bonds created by photodissociation and prevents the breakdown of the dyes. [REDACTED]

Quick Fixes to Last Minute Glitches: Good Optical Strength Begets Poor Mechanical Properties

Although each of the original problems had been addressed and independently resolved by the mid-1980s, the methods of resolution had created an additional problem—the modified polymethyl methacrylate was not easily machined into an optical element. In particular, polymethyl methacrylate

doped with low-molecular-weight plasticizers (to increase the host's optical strength to repetitive pulses) is much less rigid than commercial polymethyl methacrylate. Thus, the material was difficult to machine to close optical tolerances, and large elements did not retain their shapes. By changing the viscoelastic properties to accommodate repetitive pulsing, polymethyl methacrylate had been rendered unsuitable for final shaping and incorporation into active laser elements.

Scientists from the Institute of Physics in Moscow and the Scientific Research Institute of Organic Intermediate Products and Dyes turned with apparent success to chemical etching as a method of achieving an optical surface on modified polymethyl methacrylate. As revealed in technical publications in the late 1980s, chemical etching removed microscopic surface defects created by mechanical polishing. The reported optical characteristics were sufficient for incorporation into laser systems.

Attempts to incorporate modified polymethyl methacrylate into laser systems revealed one last problem. The rubbery material deformed when heated under optical pumping. Again, the scientists responded with a quick engineering solution. At a late 1987 [redacted] Manenkov stated that he had wedged slabs of modified polymethyl methacrylate between sapphire plates. This combination kept the polymer sufficiently rigid and improved the overall heat transfer rate as well. Manenkov claimed to have achieved a high repetition rate (probably above 10 pulses per second) with this configuration.

Hedging Bets: Alternative Solid-State Hosts and Lasants

Polyurethane Acrylate: Possible Successor to Problem-Plagued Polymethyl Methacrylate. As Manenkov's polymethyl methacrylate team was winding down, a new research team emerged in Kiev to pursue polyurethane acrylate as an alternative solid-state host. A surge of scientific papers appeared in the mid-1980s, written by scientists from the Institute of Physics in Kiev and the Institute of High-Molecular Compounds of the Ukrainian Academy of Sciences. The papers demonstrated that polyurethane acrylate had greater potential as a solid-state dye host than

polymethyl methacrylate in terms of ease of fabrication and overall performance. [redacted]

The key to success with polyurethane acrylate was its unique polymer chain linkages that resisted stress failure. The scientists simply formed the solid-state dye elements into a "triplex" by radical polymerization of the monomer between two plates of quartz or sapphire with optical quality surfaces. Ultrapurification of the monomer was not required nor were special additives. Also, no additional polishing or finishing was required. The reported optical strength of polyurethane acrylate was shown to be comparable with the strength of optical glass (800 MW/cm²). Without much fanfare, these component materials entered limited production in the late 1980s.

Microporous Quartz: Low-Pulse-Energy Applications. Other solid-state materials also emerged in the early 1980s. These materials demonstrated superior performance, as compared with polymethyl methacrylate, under a more limited set of conditions. In 1978, the deputy director of the Institute of Physics in Moscow, A. M. Prokhorov, and the director of the Scientific Research Institute Polyus, General Stelmakh, coauthored a landmark paper with scientists from the Institute of Precision Mechanics and Optics in Leningrad, introducing a new solid-state dye host with high optical strength. By leaching borosilicate glass in concentrated acid, they obtained a microporous quartz material. This material was shown to have nearly the same optical strength of solid quartz and could be manufactured with readily available equipment. When submerged in a dye solution, the microporous quartz became saturated with dye and solvent molecules. Laser actions could be achieved either with the solvent present or following evaporation.

With no inherent difficulties to overcome, microporous quartz solid-state dye elements entered limited production in the mid-1980s. An unclassified article published in early 1984 described the optical strength of microporous quartz already available in limited production. Single-pulse damage thresholds were

reported for the surface and the bulk material with and without dye. In all cases, the damage threshold was less than—but no lower than one-tenth—that for optical-grade glass. Impurities associated with the dye appeared to lower the optical strength of microporous quartz, and it was suggested that, by better purification of the dye solvent, the optical strength could be doubled. [REDACTED]

Nevertheless, microporous quartz could not be scaled up to high-pulse energies and, thus, was not a real competitor to the polymers. Only a thin layer of glass could be etched, dye concentrations were inhomogeneous, and the microscopic structure distorted and scattered the optical radiation. Although several laboratory applications were demonstrated, the number of scientists involved in the research decreased to just a few specialists in the late 1980s. [REDACTED]

Alternative Lasant: Limited Tunability. In the early 1980s, several competing solid-state tunable laser technologies were discovered. Ions in crystal lattices, such as alexandrite, emerged as reliable sources of tunable near infrared laser emissions. Color-center lasers extended this tunability deeper into the infrared band but provided only marginal reliability. Nonlinear optical techniques, such as optical parametric oscillators and frequency-conversion crystals, provided a completely solid-state approach to obtaining frequency-agile emission in limited spectral bands—from the near infrared through the visible spectrum. For applications requiring only limited tunability (such as some remote chemical-detection applications conducted at the Institute of Atmospheric Optics in Tomsk), these advanced technologies could compete favorably with solid-state dye lasers. But for true broad-band tunability, dye lasers remain the only viable option. [REDACTED]

Likely Applications

Target Locators, Antisensor Weapons, and Blinding Weapons

[REDACTED] solid-state dye lasers were developed to provide countermeasure resistance in military laser

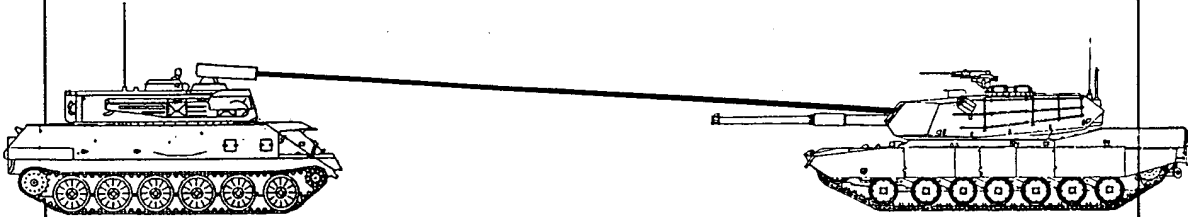
target locators and antisensor laser weapons (see figure 4). [REDACTED]

[REDACTED] a laser target locator, designed to emit multiple fixed wavelengths, was to be incorporated into an armored vehicle to be deployed on the front-lines. The original purpose of the device was to locate targets by sweeping the battlefield with a laser beam and detecting the reflection from enemy optical systems. An upgraded device was planned, incorporating a higher power solid-state dye laser, to blind or destroy sensors and to blind enemy personnel. [REDACTED]

Figure 4
Soviet Military Applications of
Solid-Dye Technology

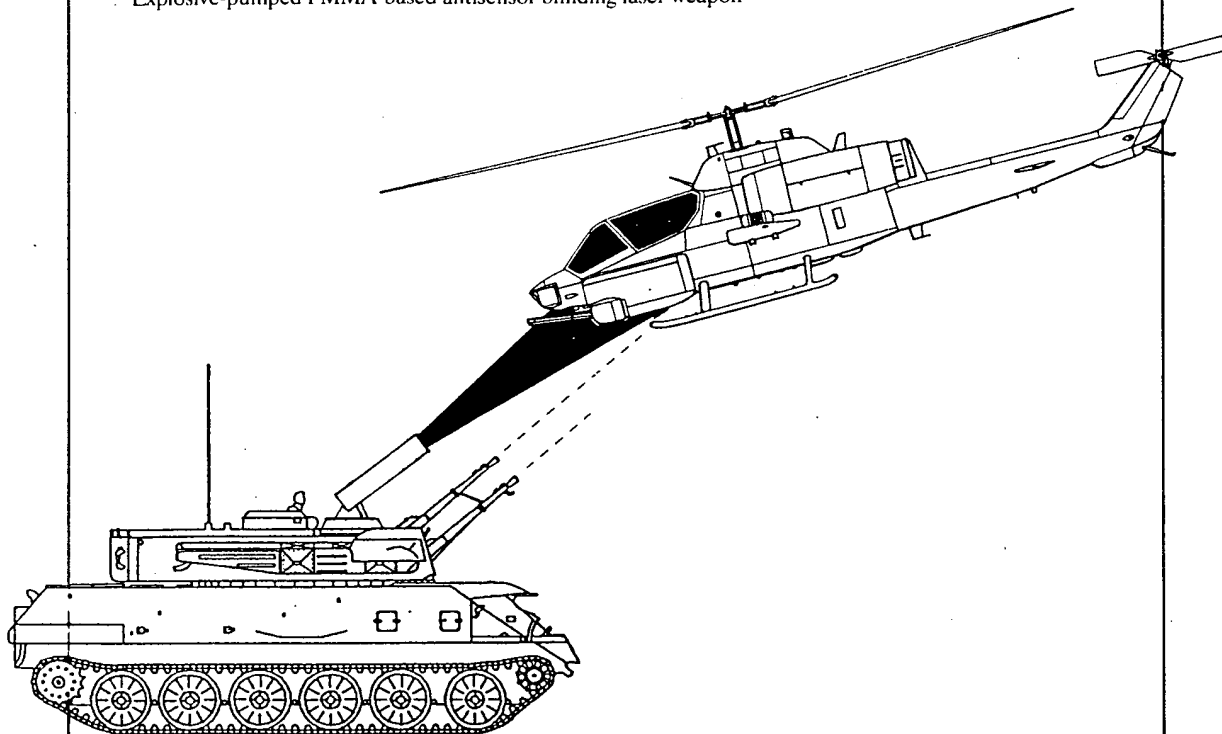
Battlefield Laser Locator

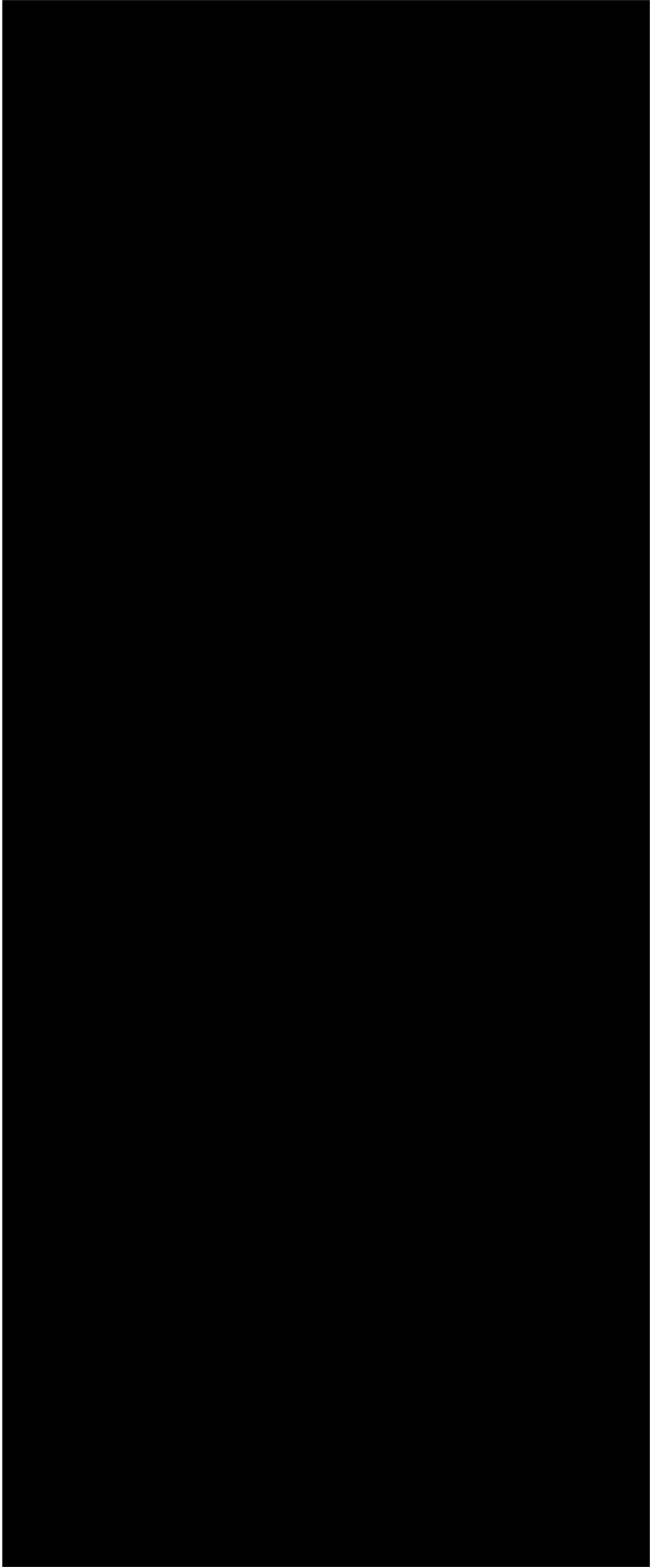
- 1st Generation: Fixed wavelength Nd-laser locator
- 2nd Generation: PMMA-based dye laser (tunable) locator
- 3rd Generation: High-energy PMMA-based dye laser locator/blinding weapon



Air Defense

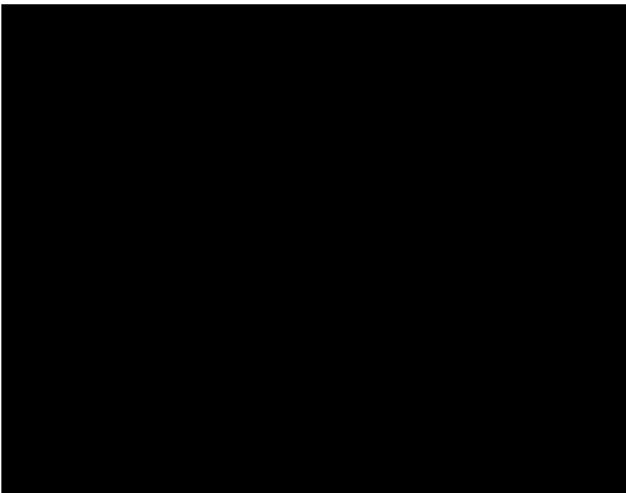
- Explosive-pumped PMMA-based antisensor blinding laser weapon








The development of a multiwavelength laser system for use as a battlefield blinding weapon would present a formidable threat to US and NATO forces for two principal reasons. First, target acquisition by gunners of most ground-based and heliborne weapon systems and by pilots of attack helicopters, tactical fighters, and ground attack aircraft is heavily dependent on vision. Thus, Soviet blinding of US/NATO gunners or pilots, even if only for a short time (often called flashblinding), could have a catastrophic impact on their ability to engage Soviet forces on the battlefield.

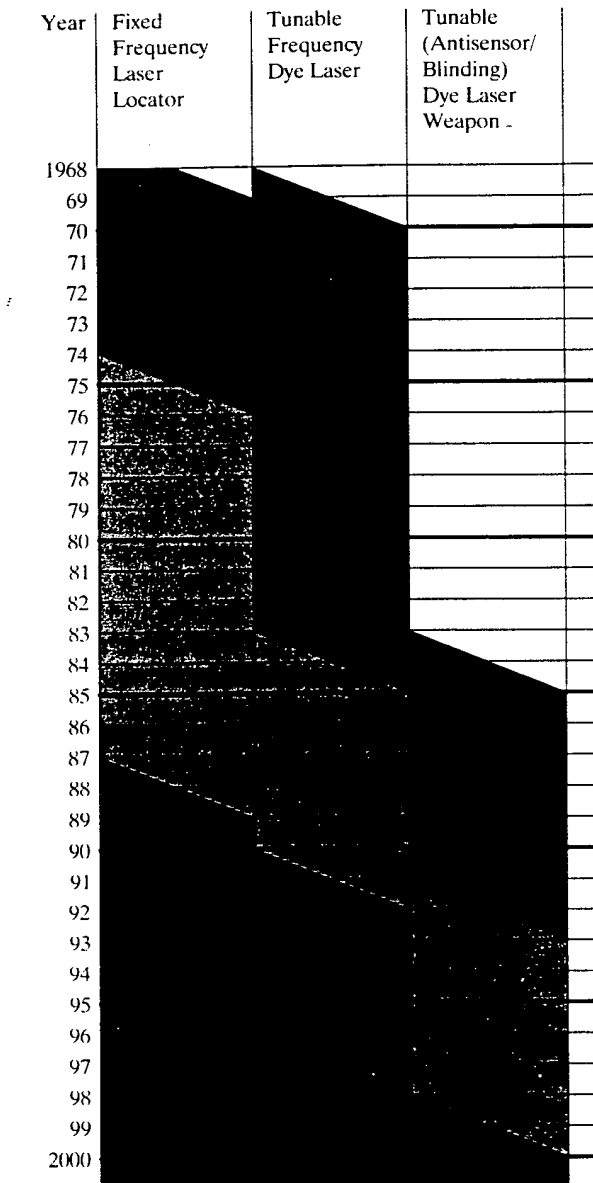
Second, dye lasers can emit optical radiation at many wavelengths throughout the visible spectrum. Because of this capability, a dye-laser blinding weapon could easily be designed to counter current US and Western laser protection systems—which protect only against specific wavelengths. Currently, protection techniques to counter a multiwavelength laser threat (such as fast optical switching or limiting the optical power transmitted through a sight) are not sufficiently mature for production and fielding.





We assess that the second-generation laser locator system probably will be a low-power (1 to 10 joules) laser, incorporating several solid-state tunable dye

Figure 5
Soviet Laser Locator Projects



Legend:  NIR (scientific research work)
 OKR (experimental design work)
 Deployment



elements 

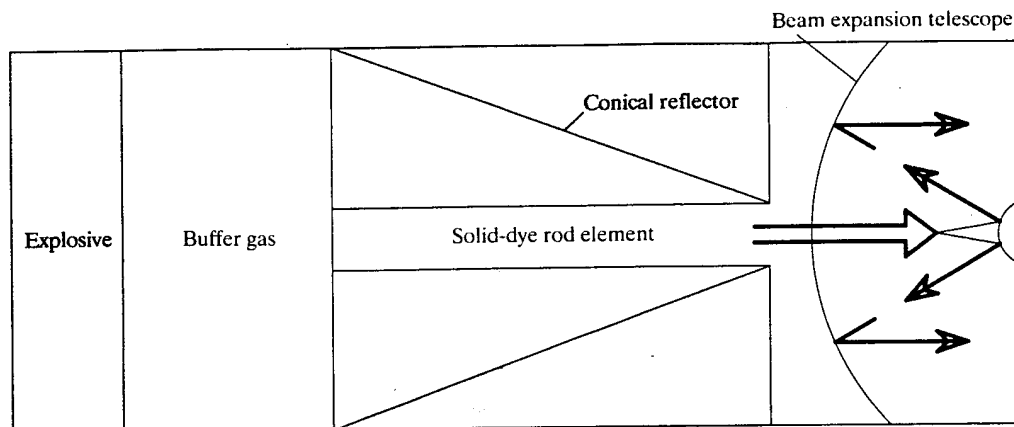
We assess that a third-generation system probably will be based on a high-power (20 to 50 joules), solid-state dye laser, 

Explosively Pumped Lasers To Be Fired From Existing Air Defense Gun Systems


 of Organic Intermediate Products and Dyes provided technical support to Astrofizika in a project to develop explosively pumped lasers. This research was conducted sometime between 1970 and 1980 and resulted in a joint award being presented to scientists from the Design Bureau Astrofizika and the Scientific Research Institute of Organic Intermediate Products and Dyes and to V. S. Zuyev of the Institute of Physics in Moscow. 

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Figure 6
Conceptual Design of Explosively
Pumped Laser



An explosive charge placed adjacent to a buffer gas provides high intensity optical excitation of the dye element for the duration of the explosion. The dye converts the broadband, isotropic radiation, into narrowband, highly directional radiation. The entire arrangement of explosive, buffer, and dye element is destroyed in the process.

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Open technical publications from the mid-1970s link V. S. Zuyev to scientists from both the Design Bureau Astrofizika and the Scientific Research Institute of Organic Intermediate Products and Dyes. These publications describe dye laser emissions from the vapor phase at high temperature and pressure—possibly related to explosive pumping—but there are no discussions of explosive pumped polymers. [REDACTED]

We believe that the Soviets could have begun OKR for explosively pumped laser weapons by the late 1970s. The published Soviet results suggest that there are no technical difficulties associated with the design or construction of explosively pumped dye lasers, and the award presented to the participating scientists suggests some degree of success. Low-optical-strength polymers can be used because repetitive pumping is not an issue. In addition, US studies have shown that explosively pumped solid-state dye lasers can be compact and rugged and can be manufactured with relatively simple equipment. [REDACTED]

Assuming that the Soviets commenced OKR in the late 1970s, deployment could have begun by the late 1980s. We believe that the Soviets most likely would have designed explosively pumped laser devices to fit the constraints of existing air defense gun systems. The inclusion of explosive laser rounds in the standard gun magazine could provide a degree of protection from airborne targets by defeating electro-optical and visual-sighting systems during an engagement. As yet, however, we have no evidence of deployment. [REDACTED]

Sales to the Third World

Consistent with the overall restructuring of the Soviet economic system, the current restructuring of Soviet scientific research programs may influence Soviet scientists involved in solid-state dye technology to pursue external markets—possibly Third World military markets. In the USSR, as in the West, there is little commercial need for solid-state dye technology.

Semiconductor lasers are used in most Soviet low-power tunable applications, such as optical-fiber communication, and solid-state crystalline lasers provide the minimal tunability needed in most environmental remote-sensing applications. [REDACTED]

Third World nations could view solid-state dye technology as a cost-effective means to defeat military electro-optical systems. In particular, the use of explosively pumped dye lasers could be used by ground forces to defend against advanced helicopters and ground support aircraft. Many Third World countries have the necessary technology base to incorporate Soviet solid-state dye elements into military systems. [REDACTED]

Outlook—Implications for the United States

A 20-year Soviet investment in solid-state dye technology indicates a strong commitment to countermeasure-resistant laser systems and to laser systems capable of defeating Western countermeasures. Although we believe dye-laser locator and laser weapon systems entered OKR during the 1980s, we cannot be sure that the Soviets actually will deploy any military laser systems based on solid-state dye technology. Although dye lasers provided the only option for tunable emissions through the early 1980s, several other options—such as crystalline lasers and nonlinear optics—have emerged in the past decade as potential candidates for future applications that require only limited tunability. Currently, Soviet military systems designers can choose from a range of technology options, depending on the wavelength range of interest and the degree of tunability desired. [REDACTED]

We do not believe that current Soviet defense cutbacks will necessarily affect Soviet tunable laser programs. In general, any decrease in the number of weapon platforms deployed is likely to increase the need for improved countermeasures resistance. The Soviets probably consider electro-optical systems like the laser locator to be good force multipliers because they allow many more targets to be engaged by a single platform. In addition to the automatic location of targets and destruction of sensors, the laser locator can serve as a target designator for a variety of other weapon delivery platforms. [REDACTED]

To defeat Soviet solid-state dye laser systems, wavelength-independent countermeasures will be required. To contend with the tunability associated with a low-power-level laser target locator, the West will have to consider ways to reduce the integrated optical cross sections of all optical systems. The reduction of the integrated optical cross section may require the development of new technologies and may degrade the performance of optical systems. [REDACTED]

To defeat tunable laser damage weapons, the West will have to consider ways to limit the intensity of light passing through optical systems. Whereas fixed wavelength laser weapons can be countered with a static, narrow-band filter, a dynamic shutter will be required to protect against tunable lasers. Furthermore, because dye laser pulses can be made extremely short (on the order of picoseconds), these shutters will have to react on an extremely short timescale. [REDACTED]

In addition to potential Soviet use of solid-state dye technology, a similar threat could emerge from the Third World or subnational organizations. If the Soviets export solid-state dye elements, they could be integrated into relatively simple but effective blinding and antisensor laser weapons. These low-cost weapons might be very attractive to Third World countries or subnational organizations for their ability to counter advanced heliborne and airborne electro-optical sensors and to blind pilots. [REDACTED]

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